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NASA's Second Generation Reusable
Launch Vehicle Program Introduction,
Status, and Future Plans

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NASA'S SECOND GENERATION REUSABLE LAUNCH VEHICLE PROGRAM INTRODUCTION, STATUS, AND FUTURE PLANS

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ABSTRACT

The Space Launch Initiative (SLI), managed by the Second Generation Reusable Launch Vehicle (2nd Gen RLV) Program, was established to examine the possibility of revolutionizing space launch capabilities, define conceptual architectures, and concurrently identify the advanced technologies required to support a next-generation system. Initial Program funds have been allocated to design, evaluate, and formulate realistic plans leading to a 2nd Gen RLV full-scale development (FSD) decision by 2006. Program goals are to reduce both risk and cost for accessing the limitless opportunities afforded outside Earth's atmosphere for civil, defense, and commercial enterprises. A 2nd Gen RLV architecture includes a reusable Earth-to-orbit launch vehicle, an on-orbit transport and return vehicle, ground and flight operations, mission planning, and both on-orbit and on-the-ground support infrastructures. All segments of the architecture must advance in step with development of the RLV if a next-generation system is to be fully operational early next decade. However, experience shows that propulsion is the single largest contributor to unreliability during ascent, requires the largest expenditure of time for maintenance, and takes a long time to develop; therefore, propulsion is the key to meeting safety, reliability, and cost goals. For these reasons, propulsion is SLI's top technology investment area.

INTRODUCTION

The United States has more than 40 years of experience in space and is the only country with reusable launch vehicle (RLV) capabilities. The Nation has enjoyed the

benefits of scientific discovery that new forms of transportation have historically made possible. In practical terms, space transportation enables not only the robust civil exploration of space, but also the critical capacity to defend National assets while it fosters economic and technological growth across many commercial sectors—from communications to navigation, from weather forecasting to global environmental research.

NASA's SLI, managed by the 2nd Gen RLV Program office, was established in February 2001, with its first Nationwide contracts awarded in May 2001. SLI focuses on business and technical risk reduction activities that lead to a set of standards for both the business infrastructure and high-priority, high-payoff technologies, such as propulsion and crew enhancements. SLI is striving to reduce the nearly \$5 billion that NASA spends annually on space transportation. Thus, by working with the U.S. aerospace industry to design a 2nd Gen RLV that is safer and more cost effective, SLI makes a major commitment to the Nation's tradition of scientific exploration. Likewise, SLI is a sustained investment in this country's aerospace infrastructure. Both thrusts—safety and cost—are critical for U.S. leadership in space; but so, too, are insight and proper management of such an endeavor. Therefore, SLI is addressing not only sensible technology improvements, but the very fundamentals of how to optimize the space transportation business for maximum success.

The SLI is reducing the risks inherent in an advanced research and development program of this magnitude while fostering a fair business environment for industry and ensuring the wise use of valuable resources. Through teamwork with its partners in the U.S. aerospace industry, academia, and the military, NASA contributes its experience in space transportation systems research and development to enable a new generation of space transportation capabilities (see Fig. 1).

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Fig. 1. A fully reusable two-stage-to-orbit RLV concept.

The fundamental work funded by SLI is the initial stage required to formulate realistic plans for the FSD and flight stages to follow (see Fig. 2). Program milestones that lead to the FSD decision include the Interim Architecture and Technology Review (IATR), Systems Requirements Review (SRR), Preliminary Design Review (PDR), and Critical Design Review (CDR).

Activities now underway across NASA and the country will result in two competing space transportation system

architectures—complete to the PDR—supported by a portfolio of advanced, high-payoff technologies, such as long-life rocket engines, robust Thermal Protection Systems (TPS), sophisticated diagnostic software, and crew-related enhancements. In its two-fold approach, SLI is *designing* complete space transportation systems that can fulfill basic civil, commercial, and military mission requirements while *developing* the technologies needed to build and operate the system that will be chosen for FSD in 2006. SLI is not just a technology program; rather, it embodies the expansion of business, scientific, and technological capabilities by designing, building, and testing hardware along with preliminary designs for a new century of space transportation and space-based progress.

SLI embodies NASA's strategic goal to focus resources on core science and exploration by reducing the cost of access to space. Based on the latest marketing research and current technology readiness levels, the Program was planned jointly with the U.S. aerospace industry. The Program budget is \$4.85 billion through 2006 (refer to Fig. 2). To optimize the Nation's investment, NASA is working cooperatively with the Department of Defense (DoD), primarily the U.S. Air Force (USAF), to identify areas of technology convergence for civil and defense missions. The recently completed 120-day study validated significant potential for a more synergistic approach to a National RLV strategy. To maximize investment, SLI

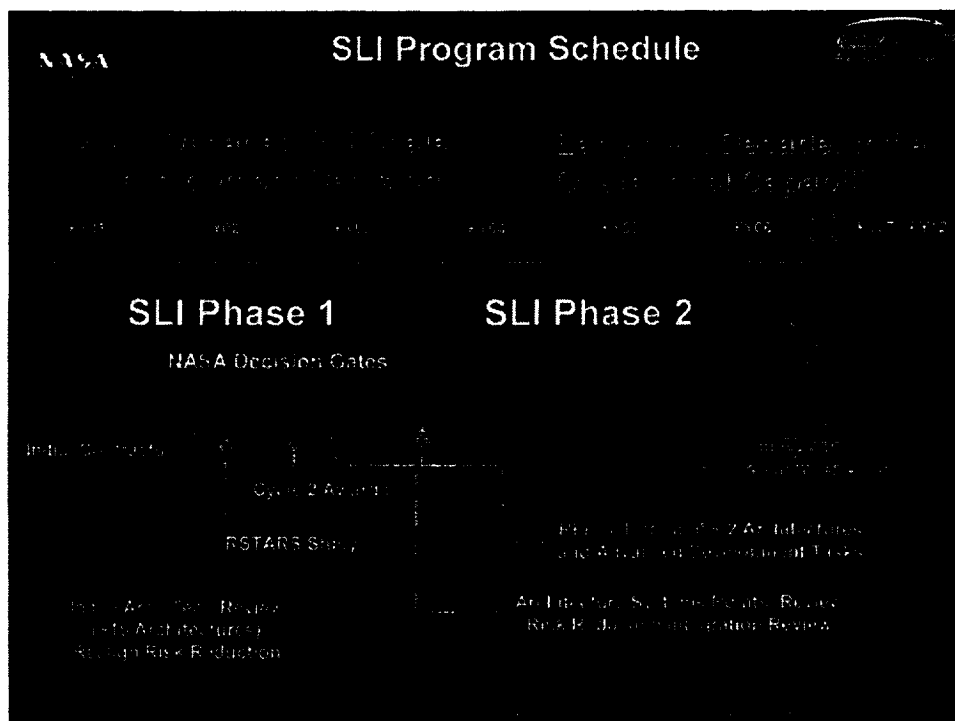


Fig. 2. SLI Program schedule with budget and milestones.

supports the effort to share mutually beneficial technologies between Government agencies.

ARCHITECTURE DEFINITION

Architecture Definition focuses on the business and technical requirements for defining and ultimately developing a 2nd Gen RLV and support capabilities. Such an overall space transportation system includes not only a reusable Earth-to-orbit launch vehicle, but also on-orbit transfer vehicles and upper stages, mission planning, ground and flight operations, and both on-orbit and on-the-ground support infrastructure. Successful development of an innovative, effective, and cost-conscious system will revitalize our Nation's space transportation industry by revolutionizing its capabilities.

In May 2001, competitive contracts were awarded under NASA Research Announcement (NRA) 8-30 to develop several candidate architectures along multiple competing technology paths while considering emerging technologies that would be integrated into the chosen design. The technologies are evaluated as they are matured to ensure that architecture needs are met. NASA, through in-house analyses, evaluates concepts from U.S. aerospace and university teams dedicated to transforming theory into reality.

Theory, however, is bounded by strict criteria and evaluated based on a proposed architecture's ability to successfully accomplish Design Reference Missions (DRM). Using the systems engineering capabilities unique to NASA, DRMs that specify various parameters, such as payload mass, orbital inclination, and on-orbit operations, are developed for each mission statement and provide a common point of reference for quantifying the success of a candidate architecture. Figures of Merit (FOM) provide a measure of system effectiveness across three broad categories: safety and reliability, economics and cost, and technical performance.

There are two primary mission needs: *International Space Station (ISS)* logistics, and payload delivery to low-Earth-orbit and other orbits. Analysis missions include such activities as delivering, assembling, servicing, boosting, retrieving, and possibly returning space platforms, modules, or orbital assets; deorbiting space debris or inactive spacecraft; and rescuing crew. Analysis missions will be utilized to assess candidate architectures for the possible inclusion of other missions as well. This mission derivation process clearly states the expected level of performance for the new space transportation system.

During the first quarter of 2002, multiple architecture designs were presented by each contractor team at the IATR (see Fig. 3). This review validated the contractors'

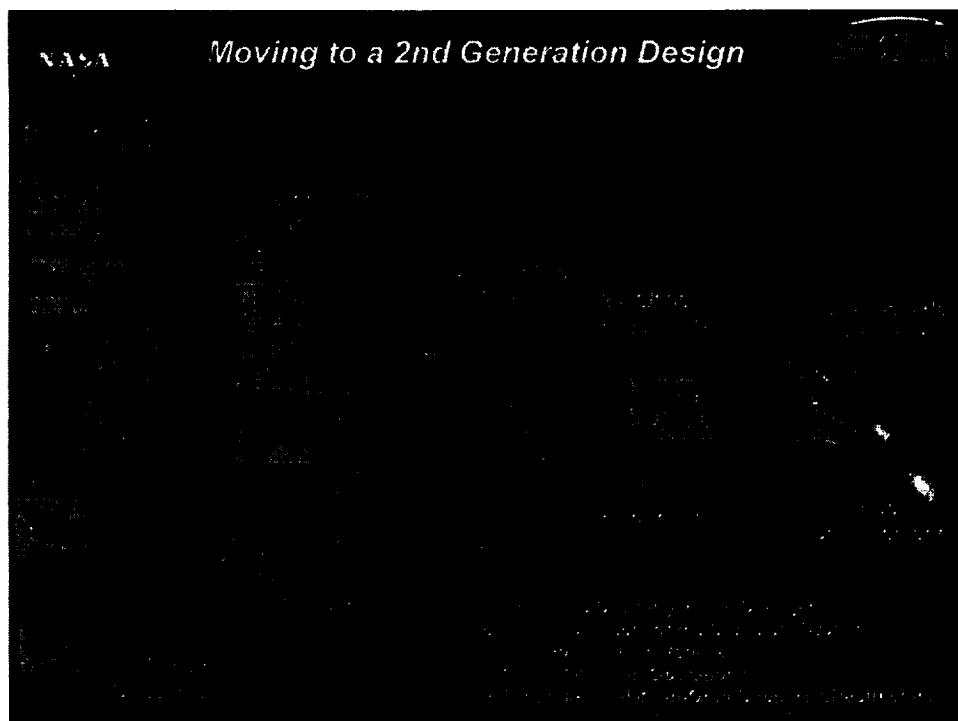


Fig. 3. Process of narrowing architecture designs.

results and provided critical feedback regarding concurrent technology development. The number of concept architectures was reduced to those presenting the most potential for satisfying primary mission requirements and goals. Before the SRR in Fiscal Year 2003 (FY 2003), as system requirements are refined and finalized, vehicle designs will be further reduced to one each for the three prime contractors.

INTERIM ARCHITECTURE AND TECHNOLOGY REVIEW

At the end of the NRA 8-30 contract base period, the IATR provided a decision point for the Program to make architecture selection and technology content decisions. Results compiled from the additional Interim Architecture Review process and from further systems engineering and economic analyses were used to determine the best course of action for achieving the next scheduled SLI milestone. Decisions were based upon a project's (or task's) relevance to the architectures, its benefit to the Program, whether it promotes competition, and its ability to successfully accomplish DRMs while satisfying mission-level FOMs.

Data provided by the contractors were analyzed by an independent, in-house review team. In most cases, the results confirmed those presented by the contractors; in other instances, possible erroneous data were identified and flagged for further analysis. Gaps in technical capabilities were also identified during this process; those deemed high priority will be filled by NRA 8-30 Cycle II awards. Gap priority is based upon the *need* for the technology by the architectures and the technology's probability of readiness by 2006, when the FSD decision will be made.

Contracted tasks involve nine specific areas: (1) Architecture Definition, (2) Airframes, (3) Vehicle Subsystems, (4) Operations, (5) Integrated Vehicle Health Management (IVHM), (6) Flight Mechanics, (7) Propulsion, (8) Flight Demonstrators, and (9) NASA Unique. Work in these areas comprises 59 tasks, of which 50 had exercisable options. Decisions about exercising these options were made using the information presented during the IATR. Eight options were rescoped to better align technology development efforts, while six options were not exercised. Those options not exercised either did not or could not meet the Program's requirements, or they did not offer a benefit significant enough to justify increased cost or risk. For example, architecture assessments show weight savings by using composite tanks, but developing, operating, and maintaining this type of tank introduces significant risk that outweighs potential benefits. Since liquid oxygen/kerosene (lox/RP) emerged

as a first-stage propulsion option, the need for composite cryotanks has been reduced. Composite tank studies have been rescoped to allow further study of the issues related to risk, as well as noncryo application for RP engines. The IATR was a comprehensive evaluation that yielded valuable information, and using that information, critical decisions were made.

SYSTEMS REQUIREMENTS REVIEW

The second major milestone in the development of a 2nd Gen RLV is the SRR, which begins in November 2002. This 3-month process begins with in-house, independent analysis of contract deliverable data. This activity helps ensure that, prior to proceeding to the system and preliminary design phases of the Program, system- and element-level design and interface requirements are adequately and appropriately designed. The SRR confirms that the requirements defined in the system specifications are sufficient to meet Program objectives, and that systems engineering and integration processes are defined and implemented.

The SRR has two main goals: (1) to establish a baselined set of converged requirements to support subsequent design activities, and (2) to review the chosen architectures against functional and performance requirements to determine if requirements need to be altered. In addition, architecture concepts/designs will be examined to ensure that the appropriate primary and alternate path actions are working and on track to mitigate risks, especially when the success of a specific concept/design depends on successfully developing an underpinning technology. This is especially pertinent to propulsion, where all components must integrate and work flawlessly for a successful launch and on-orbit maneuvering.

Ongoing technology development activities will be evaluated during the SRR to ensure that progress is being made. Technical Performance Measures are used to help define requirements in terms of form, fit, and function for architecture assessment, identifying necessary changes to technology specifications. The SRR will also assess the probability of a technology reaching maturity by 2006, and align technology development needs with the needs of the architecture concepts.

The SRR objectives are to:

- Establish and validate that the allocated functional system requirements are optimal to satisfy mission goals and objectives with respect to requirements trades and established evaluation criteria

- Identify technology risks and the plans to mitigate those risks
- Present refined cost, schedule, and personnel resource estimates.

Successfully accomplishing these high-level objectives will provide the basis for continuing development of the 2nd Gen RLV and the technologies required to support the system, leading activities into the System Design Review (SDR) and PDR phases of the Program.

PROPULSION—THE KEY to SUCCESS

Experience shows that propulsion is the single largest contributor to unreliability during ascent and presents the greatest *operational* risk. Data indicate that as much as 50 percent of the Space Shuttle processing time is in the TPS, main engines, and servicing the fluid systems used in the Reaction Control System (RCS) and Orbital Maneuvering Systems that help maneuver vehicles while on orbit. Since two of these three cost factors relate to propulsion, and because it takes a long time to develop, propulsion holds the key to meeting safety, reliability, and cost goals. For these reasons, propulsion is SLI's top technology investment area.

In keeping with the Program's lean enterprise theory, buy down of propulsion risk reduction will increase each year in correlation with competitive selection of propulsion systems and subsystems. Ultimately, this will save millions of dollars in overall development cost. SLI baselined and benchmarked itself against a number of similar technology investment programs; choosing the Joint Strike Fighter (JSF) is one example of a successful design, development, test, and evaluation (DDT&E) program. By using lean thinking concepts to reduce variability in DDT&E efforts, the JSF program proved that 70 percent of the total ability to improve life-cycle costs (LCC) is in up-front design. Prototype design eliminates and/or reduces failure modes and design uncertainty, and it enables requirements control and proper materials selections. Cost of DDT&E for the Space Shuttle Main Engine (SSME) totaled \$3.6 billion; this figure was used as a baseline for propulsion development. Seventy-five percent of SSME development was in the test/fail/fix approach, with the majority of the burden being unpredicted; this resulted in cascading uncertainty within the cost models. Based on SLI's approach and propulsion investment of about \$500 million, development cost benefits are expected to be as much as \$1.5 billion.

During the past year, project reviews have ensured that high-priority propulsion systems are on track toward

developing prototype main booster engines, on-orbit nontoxic reaction control thrusters, advanced materials, and environmentally safe propellants. Decisions were made concerning how to better focus investments to reflect the needs of potential vehicle architectures that are being designed in parallel. Examples of major propulsion accomplishments include design reviews on main engines and system tests on reaction control thrusters that use nontoxic propellants, which can create a safer environment for ground operators, lower cost, and increase efficiency with less maintenance and quicker turnaround time between missions.

During FY 2002, the Propulsion effort is continuing to reduce the risk of high-priority technologies and reviewing major hardware components to define a clear design process. In preparation for the architecture SRR (beginning November 2002), risk reduction activities conducted for propulsion will benefit the Program. Overall risk reduction activities for propulsion systems demonstrate improvements over existing technologies; propellant cross-feed systems and engine health maintenance features are examples. Additional high-priority technology efforts include jet-powered propulsion for return of the first stage, which will allow booster flight farther down range and to higher velocities. Jet-powered propulsion may help to lower the overall weight of the vehicle by reducing the weight of the second stage. Plans are also underway to, by the end of FY 2002, staff a Crew-Escape and Survival Propulsion Project office which will focus on reducing the risk of safe crew-escape propulsion systems that use advanced solid, liquid, or hybrid propulsion techniques. Viable main engines—engines with greater thrust capabilities, safer operations, and lower maintenance costs than the SSME—will be selected from several competing designs. Propulsion projects will be refocused to ensure seamless integration with vehicle requirements. Based on architecture needs outlined in the IATR, contract options have been exercised to include designing an engine that uses easier to handle lox/RP. Using lox/RP in the first stage of launch could result in a safer overall architecture with a reduced turnaround time for the next launch.

Potential benefits can be derived from using both RP- and hydrogen-powered engines. While RP has the advantage of being a denser fuel than LH₂, hydrogen has a higher specific impulse, although the larger hydrogen fuel tank is a potential disadvantage. The SLI Program has yet to make a decision about which first-stage fuel best meets the SLI goals of improving access to space through systems that are safer and less expensive. Multiple main engine designs utilizing both fuel requirements are being considered for a 2nd Gen RLV.

The RS-84 main engine design uses lox/RP, which has lower maintenance costs and provides a safer overall engine design. Two lox/LH₂ main engine designs are also being considered: RS-83 and the Cooptimized Booster for Reusable Applications (COBRA). The RS-83 is a staged combustion engine that uses advanced materials, including powdered metallurgy, to produce cost-effective hardware that outperforms existing engine components. Technology advancements in turbopumps, avionics, and hydrostatic bearings allow the 650,000-lb-thrust prototype engine to operate more efficiently than the SSME and do so with hardware that is easier to maintain and offers greater reliability. In addition, the engine will use fewer parts that weigh less than existing engine parts. The COBRA design offers a 600,000-lb-vacuum-thrust engine design with a single-liquid, fuel-rich preburner; high-pressure turbopumps; low-pressure turbopumps; and a channel-wall nozzle. All engine designs support multiple architectures.

Since propulsion is one of the most critical technology areas, improvements present immediate benefits. A new electronics technology, the electromechanical actuator (EMA), is proving to be advantageous for the main propulsion system planned for a 2nd Gen RLV. This new electronic system provides the force needed to move valves that control the flow of propellant to the engine. EMA control system technology is a potential alternative for and improvement over the older pneumatic and hydraulic fluid systems currently used by the aerospace industry.

Hydraulic actuators have been used successfully in rocket propulsion systems; however, when high pressure is exerted on such a fluid-filled hydraulic system, it can cause expensive and potentially dangerous leaks. The EMA does not contain fluid to create pressure but is activated with precise electric pulses that "tell" it when to move and when to stop. Hydraulic systems must also sustain significant hydraulic pressures, typically in the range of 3,000 to 6,000 lb/in² in rocket engines, regardless of demand. Unlike fluid-filled hydraulic lines, the electrical circuits in an EMA do not freeze in the vacuum of space, thereby requiring less on-orbit maintenance.

Many new engine concepts proposed by the aerospace industry for a 2nd Gen RLV use EMAs; so, in 2001, a series of tests was performed at NASA's Stennis Space Center to gather more performance data. The aerospike engines already on the test stand at Stennis were used to explore this relatively new technology today, saving valuable time later. These data are critical to support the use of such improved actuators on future launch vehicles. Successful development of EMA control systems will

advance propulsion technology and potentially benefit the entire 2nd Gen RLV Program by reducing risk and improving the safety ranking in the engine, thereby the safety of the entire launch vehicle.

Based on successful initial testing of the two competing RCS thruster approaches (see Fig. 4) and basic technology for high-concentrate peroxide, propulsion RCS is focusing on less toxic peroxide/RP and lox/ethanol propellants. These will ultimately lower costs of ground operations, since handling requirements may not be as exhaustive as for the more toxic fuels. Through a partnership with the USAF, safer peroxide and fuel combinations are being studied for use in the upper stage propulsion systems—basic research is complete and requirements have been identified through successful testing of materials compatibility and detonation. Next year, additional research will determine appropriate environmental safety hazard risk reduction requirements. Decisions on RCS propellants and their application will be subject to the overall SLI propulsion program decisions that will be made by the end of September 2002.



Fig. 4. RCS test firing.

In FY 2003, propulsion elements will begin the advanced phases of sub- and full-scale testing, culminating in a CDR of competing engine systems. The CDR will establish finalized design concepts to build the engine system; 90 percent of prototype and existing hardware drawings will be completed by this time. This will ensure that the propulsion systems and architecture concepts are parallel and ready to proceed—within budget and on schedule—to ground testing beginning in FY 2005 and continuing through FY 2006.

From FY 2004 to FY 2006, significant prototype hardware development and testing of main engines, RCS thrusters, nontoxic propellants, and crew-escape

propulsion, aimed at enabling an FSD decision, will take place. Major milestones during this period include prototype subsystem testing of the auxiliary propulsion test article, prototype main engine design, manufacture, test, and integration, resulting in initiation of flight engine design. Having advanced, operable propulsion systems at this point in the research and development cycle will ultimately allow the Agency to go forward with the FSD of the optimum architecture design supported by technologies with significantly reduced risks.

INTERDEPENDENT TECHNOLOGIES

Propulsion, as is the entire 2nd Gen RLV space transportation system, is interdependent with myriad subsystems and enabling technologies. If the propulsion system cannot break the bonds of gravity to safely deliver a payload, a revolutionary space vehicle design will not matter. Likewise, a revolutionary engine cannot succeed if all other subsystems do not work cooperatively. Airframes, vehicle health monitoring, flight demonstrators, and crew safety systems are just a few critical technologies that affect propulsion development.

Airframes

Airframe technologies include developing and optimizing the TPS and structures, such as tanks and wings. Research and design activities include assessing vehicle aerodynamics and aerothermodynamics which control the loads and temperatures to which the vehicle will be subjected.

Thermal Protection System

TPS technologies are included in SLI's extensive airframe research, investigating ways to radically improve both aerodynamics and aerothermodynamics. Significant improvement has been made in hot-powder process manufacturing, which helps eliminate flaws in monolithic ceramics, known as Ultra-High-Temperature Composites (UHTC). This material, when used as a TPS on the sharp leading edges of a space vehicle (e.g., wings), provides more abort coverage, which improves crew safety. Essentially, UHTCs possess a unique set of material properties including unusually high thermal conductivity, good thermal shock resistance, and modest thermal expansion coefficients that make them particularly well suited for sharp body applications in hypersonic flows. Sharp leading edges (≤ 1 cm) could enable an entire new design space for hypervelocity vehicles with decreased drag, increased cross-range capability, and reduced cost to orbit.

Metallic TPSs are also being evaluated based on success of the X-33 technology demonstrator project. Metallic TPSs will eliminate the need for time-consuming waterproofing in today's operations.

Tanks

Based on preliminary architecture assessment results, lessons learned, and the inclusion of RP, metallic tanks are now the most viable design. The metallic tank effort has been increased and restructured to focus on critical technology needs, such as self-reacting friction stir welding in circumferential and complex curvature demonstrations. Preliminary results using *composite* tanks in cryogenic applications show only minimum weight savings over metallic tanks, but with increased operation and maintenance issues. Therefore, the composite cryotank effort is being focused on the operability issues (related to risk as well as noncryo application for lox/RP engines) and overall benefit to the architectures.

Integrated Vehicle Health Management

It is critical to monitor the system health of the entire space launch system, not just the engine, throughout every phase of operation—preflight, in-flight, and postflight. For example, the Engine Health Management System (EHMS) will be able to detect and track a minute flaw in engine performance within microseconds. It will analyze propulsion data and, should less-than-optimal performance occur, may select to safely shut down the vehicle's main engine. A high-level IVHM system design has been completed, and it demonstrates the potential use for model-based reasoning software in the system.

Risk reduction studies for an EHMS provide information directly related to the IVHM system. Similar in concept to the new SSME Advanced Health Management System, IVHM will provide objective results that can dramatically improve routine operations. SLI is working with the Space Shuttle Program to determine complementary activities in this and other areas.

Flight/Technology Demonstrators

Before an advanced space transportation system can be built, selected hardware and software technologies must be flight tested in a relevant ascent, orbit, and reentry environment. Flight demonstration is essential to obtain these environments and demonstrate these technologies in an integrated system. Success in the DC-XA project has established the value of flight tests. SLI is supported by multiple integrated flight demonstration projects, including the X-37, Kistler K-1, and Demonstration of Autonomous Rendezvous Technology (DART).

The X-37 integrates advanced technologies for testing in real-world flight environments. In 2001, the X-37 Project, using a prototype look-alike vehicle called the X-40A, completed a highly successful series of seven drop-tests in the initial atmospheric phase. Such testing contributed important data needed to complete the X-37 design; this information is now part of the RLV knowledge base. The next phase of the X-37 Project will be to conduct a series of five unpowered approach-and-landing flight tests. These tests are a necessary precursor to orbital flights and are currently targeted for 2004.

The Kistler K-1 is a two-stage, privately developed vehicle designed for full reusability. Powered by Aerojet/Russian NK-33 and NK-43 engines, the vehicle is 121 ft (36.9 m) long and 22 ft (6.7 m) in diameter, weighs ≈841,000 lb (382,300 kg), and is launched from Australia. The Kistler K-1's reusability and modular design enables it to be used for flight experiments. NASA developed a unique commercial contract with Kistler to purchase flight test data. This is an example of how SLI is addressing technical and commercial needs.

DART will test proof-of-concept technologies required for spacecraft to locate and rendezvous with another spacecraft without direct human guidance. While NASA has performed remote rendezvous and docking missions in the past, astronauts have always piloted the spacecraft. Autonomous rendezvous technologies represent a critical step forward in U.S. capabilities and will lay the groundwork for future reusable manned and unmanned launch vehicle operations. Future applications of this technology include cargo delivery and space taxi operations for the ISS and other on-orbit activities, such as satellite assembly, retrieval, and servicing missions.

Reusable Space Transport and Return System

Human space flight remains a challenging endeavor in spite of advances in aerospace technology. SLI deals with all aspects of astronaut safety, including escape and survival enhancements, a weight-saving inflatable airlock, and the operational features unique to human space flight. This is the Program's top *design* risk area, and contractor competition is wide open.

Current on-orbit 2nd Gen RLV designs carry either crew or cargo. SLI is evaluating the best way to address crew transfer and crew rescue capabilities. The Reusable Space Transport and Return System, in the NASA Unique project area, will design one vehicle that serves both purposes. NASA Unique technology projects are also looking at ways, from prelaunch to landing, to ensure safe extraction of the crew across the flight envelope. Such a

system will interact with the crewed vehicle via flight performance health detection sources that can initiate crew escape in the event of an in-flight failure.

FUTURE PLANS

A second round of contract awards to fill design and technology gaps identified in the IATR process will begin in the second quarter of FY 2002 under NRA 8-30 Cycle II. SLI's first round of awards (NRA 8-30 Cycle I) in May 2001 was valued at \$791 million; 22 prime contractors and over 150 subcontractors received awards. An additional \$94.6 million was awarded in December 2001. In addition to propulsion, Cycle II will focus on crew enhancements, coordinated by the NASA Unique Systems Project, and integrated flight demonstrators to further mitigate the risks associated with developing a 2nd Gen RLV to serve NASA, commercial, and DoD needs. The investment is estimated to be ≈\$500 million budgeted over the next 4 years.

Buying Down Risk

As SLI progresses, it will continue to deliver accomplishments that buy down the business and technical risk of FSD. In the 2002 to 2003 timeframe, the SRR process will reduce the field of architecture concepts to a single design from each of three contractors, while further defining the specific technologies that require selected investment. Independent reviews will be conducted periodically to validate SLI progress and approach.

In the 2004 to 2005 timeframe, architecture plans will be refined; both technology and business cases will continue to be analyzed, and strides will be made in focused ground and flight testing for prototype engines, NASA-unique safety features, airframes, and automatic vehicle health monitoring, among others. An SDR will establish another level of fidelity among the architecture designs and technology readiness levels. Independent reviews will also be conducted during this period.

In 2006, the two-part Formulation Phase of space transportation development covered by SLI ends and the Implementation Phase begins with an FSD decision, based on two competing launch vehicle concepts that have passed a PDR. In parallel with the FSD decision, the cost-effectiveness status will be reviewed for development, production, and operations in the aerospace industry. Recommendations will be made for applying the findings to the LCC estimates for the next generation of RLVs. Initial estimates will be based on data collected from each industry-led architecture development team.

Also in 2006, engine prototypes will be in the test stands, new TPS will be in development, and flight demonstrators will continue to integrate and test multiple technologies. Most importantly, the fundamental question, what kind of vehicle the U.S. launch industry can produce, will be resolved, and there will be a great measure of assurance as to how much it will cost to build and operate the new system. Hard-and-fast goals such as a \$1,000 per pound to orbit cost and a 1-in-10,000 probability of loss of crew are admirable targets, but they are not the only measures of success. For example, attaining a 1-in-5,000 safety factor would not indicate failure; rather, it would reflect the realities of the current analysis of both Government and contractor team members while offering great improvements over current capabilities.

Fundamental research and risk reduction activities have already yielded valuable information that could not have been predicted a year ago. Over this past year, architecture concepts were validated, technology development data were analyzed against those credible designs, and original mission requirements were challenged and refined. For example, crew and cargo have been separated to build in safety and cost efficiencies. Metallic tank activities were increased, composite tank work reduced, and RP propulsion systems included, based on overall systems analysis. Autonomous operations, self-diagnosing health monitoring systems, and quicker turnaround processing will allow launch rates to rise and reduce the cost per launch. Fly-back booster propulsion will enable the multistage vehicle to be fully reusable. These are just a few of many meaningful developments.

Program reviews are comprehensive examinations of project status. The IATR at the end of the first contract period extracted information needed to exercise some options and redefine others. For example, a contract was exercised to develop a propulsion first stage using lox/RP as a fuel, driving the decision not to pursue composite tanks. As a result, work was rescoped in favor of metallic tanks. These two developments could not have been predicted a year ago without the Government-funded research conducted by SLI and the 2nd Gen RLV Program; both underscore the Program's mandate for fully understanding the questions before reaching solutions.

The Program will ultimately succeed because it employs sound business practices and a rigorous systems engineering process, which is the pivotal point where the architectures and technologies converge. The Program has the proper insight into the many designs and development areas involved, and it has made critical decisions based on the benefit and relevance to the Agency's overall goals for dramatically improving access to space. Systems

engineering defines and integrates key components that enable the credible development and operation of a safe and cost-efficient 2nd Gen RLV and support infrastructure. It provides the tools that project how much it will cost to field the new system and make it fully operational next decade.

CONCLUSION

The United States and the world have benefited from scientific discovery and breakthrough exploration that new forms of transportation have historically made possible. In practical terms, space transportation enables the robust civil exploration of space while fostering economic and technological growth across many commercial sectors. NASA's SLI is not just new technologies—it is the promise of a revitalized aerospace industry supported by efficient, reliable vehicles from a NASA Program that is deeply committed to cost accountability and delivering value for the money entrusted to its keeping.

The Space Shuttle has served with distinction for over 20 years, but the system requires labor-intensive work and is costly to operate. It also offers an extensive knowledge base upon which to build a firm foundation for a new generation of safer, more reliable, and less expensive space transportation specifically designed for a new generation of missions and markets.

In summary, NASA's SLI is reducing the risks inherent in an advanced research and development program for space transportation while fostering a fair and competitive business environment for industry and ensuring the efficient use of valuable resources. Through teamwork with its partners in the U.S. aerospace industry, academia, and other Government agencies, SLI is on course to reduce the risk of developing a safer, more reliable, and less expensive space transportation system that will enable NASA to pursue its ultimate goals—to understand and protect our home planet, to explore the universe, and to inspire and empower generations of explorers to come.

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